

The Sensor Test for Orion Multi-Purpose Crew Vehicle Relative-Navigation Risk Mitigation Development Test Objective

John A. Christian, Johnson Space Center

Heather Hinkel, Johnson Space Center

The primary relative navigation sensor for the Orion Multi-Purpose Crew Vehicle (MPCV) will be the Vision Navigation Sensor (VNS). As such, the VNS will be a critical instrument in allowing Orion MPCV to perform the essential tasks of rendezvous, proximity operations, and docking with the International Space Station (ISS). The VNS—built by Ball Aerospace & Technologies Corp. (headquartered in Boulder, Colorado)—is a cutting-edge Flash Light Detection And Ranging (LIDAR) system that is expected to detect reflectors on the ISS from as far as 5 km (~3.1 miles) away. These data will be used by the Orion MPCV navigation systems to calculate the relative position and velocity of Orion MPCV during these flight phases. The VNS is also capable of simultaneously tracking enough reflectors to compute relative attitude at ranges less than 15 m (49 ft) while on an ISS approach profile.

After studying the lessons learned from relative navigation sensors on many previous flight programs and performing ground test programs, engineers at Johnson Space Center (JSC) determined it was essential to perform an on-orbit test of the VNS sensor. This was the origin of the Sensor Test for Orion MPCV Relative-Navigation Risk Mitigation (STORRM) Development Test Objective (DTO), which flew on the STS-134 space shuttle mission to the ISS in May 2011. In addition to the VNS, the STORRM DTO provided on-orbit testing of the new high-definition Orion MPCV docking camera. The VNS and the docking camera were tested on a nominal shuttle approach trajectory during docking on Flight Day 3, and on an Orion MPCV-like approach trajectory during an unprecedented re-rendezvous following undock and fly-around of the ISS. Development of the STORRM DTO sensor hardware, avionics (containing power distribution and data recording), support infrastructure, and data analysis algorithms was a 3-year collaboration between JSC, NASA Langley Research Center (Hampton, Virginia), Ball Aerospace & Technologies Corp., and Lockheed Martin (headquartered in Bethesda, Maryland).

LIDARs have a long history of use as relative navigation sensors. The space shuttle, for example, used a scanning LIDAR system called the Trajectory Control Sensor (TCS) to track a single ISS-mounted reflector at a given time. In a scanning LIDAR system, a narrow laser is scanned

throughout the instrument's field of view, and it will identify a reflector and return the bearing and range to only that one reflector. Unlike scanning LIDARs that can only track one reflector at a time, a Flash LIDAR system such as the VNS has no moving parts and can track many reflectors at one time. A Flash LIDAR sends out a broad laser pulse and captures the return with a camera-like detector system. The result is two digital images of: (1) the intensity of the laser return at each pixel location; and (2) the measured range at each pixel location. Therefore, a Flash LIDAR system creates a three-dimensional map of the observed scene (from the range measurements) and a corresponding map of the intensity of the laser return. Because the reflectors were designed to be highly reflective in the VNS laser wavelength, the reflectors should be among the brightest objects in each VNS intensity image. The STORRM DTO used JSC-developed image processing algorithms to automatically detect the reflectors in the VNS images (figure 1). The VNS data will be compared to the TCS data, post-flight.

Astronauts attached specially designed reflectors built at NASA Langley Research Center to the ISS docking target and standoff cross to properly test the VNS during space shuttle mission STS-131 in April 2010. These reflectors are highly reflective at the VNS laser wavelength, but are opaque (not reflective) at the TCS laser wavelength. This reflector pattern will be used to demonstrate the ability of the VNS to track multiple reflectors and compute relative position and attitude from 15 m (49 ft) through docking on an ISS approach trajectory.

After the launch of STS-134 in May 2011, NASA performed a checkout of all the STORRM hardware and software on Flight Day 2. Then, the VNS and docking camera collected data during the rendezvous with the ISS on Flight Day 3. During this time, screenshots of the STORRM software application as well as health and status information of the STORRM hardware components were downlinked to the Mission Control Center at JSC through a near real-time TV system called Sequential Still Video. This system provided information about how well the STORRM data recorders, VNS, and docking camera functioned during the rendezvous.

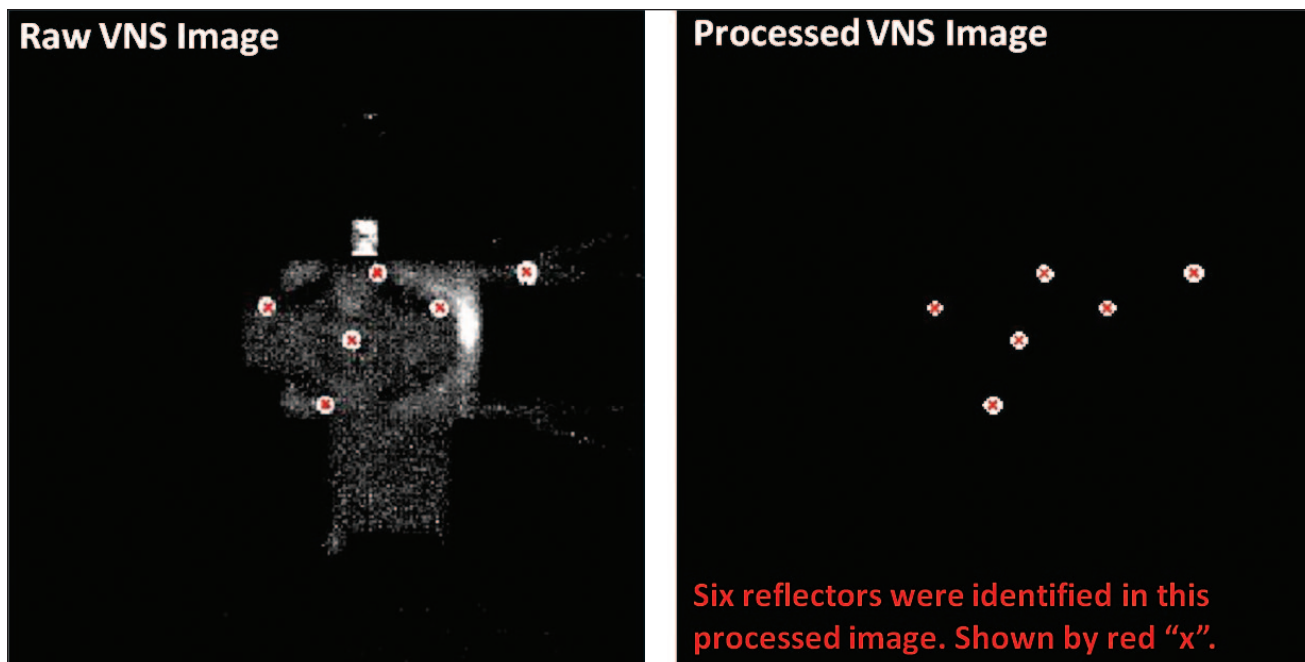


Fig. 1. The Vision Navigation Sensor (VNS) is capable of detecting the six reflectors (five Sensor Test for Orion Multi-Purpose Crew Vehicle Relative-Navigation Risk Mitigation-like reflectors, and one 5 cm (2-in. blue street reflector) mounted on the docking target at a range of about 4.5 m (14.7 ft) in this test image from April 2010.

After the shuttle docked with the ISS, a small set of prioritized data was retrieved from the STORRM drives and downlinked to the Mission Control Center. These data were then analyzed by STORRM analysts to determine whether the VNS and docking camera operated as expected during the Flight Day 3 rendezvous. The results of this analysis informed the STORRM team of any changes that needed to be made to the VNS or docking camera settings, which could be modified through configuration files before the re-rendezvous on the day of undocking. Additionally, before the standoff cross was removed from the docking target, the crew took a number of photographs of the target from several angles. These images were used for a photogrammetry analysis to determine the actual location of each reflector on the docking target to within 3 mm (0.12 in.).

The STORRM hardware was powered on again before undocking from the ISS. The VNS collected data throughout the ISS undocking, fly-around, and during the re-rendezvous on the Orion MPCV-like approach trajectory. These data allowed the STORRM team to assess the VNS performance along a trajectory similar to what is planned for the Orion MPCV and other future vehicles. The shuttle and Orion MPCV trajectories are different in a number of ways making

this a critical part of the STORRM test. The re-rendezvous took shuttle to a targeted point 305 m (1000 ft) below and 91 m (300 ft) behind the ISS. STORRM operated and collected data through 5 km (3.1 miles) on the departing trajectory.

The experience and sensor data gained by the STORRM DTO will be of great value to the Orion MPCV Program Office and to all of the STORRM team members. In addition to benefiting the development of the VNS for Orion MPCV, the STORRM DTO is also benefiting other projects using the VNS, such as the VNS Autonomous DPP Rendezvous Experiment, which is scheduled to fly to the ISS as part of the DEXTRE Pointing Package (DEXTRE is a sophisticated dual armed robot on the ISS built by the Canadian Space Agency). The maturation of this state-of-the-art sensor will make this technology available to future NASA programs (crewed or uncrewed) for rendezvous and docking. The advancement of Flash LIDAR technology also benefits the cross-cutting application of hazard avoidance, which is required for safe landing on asteroids, the moon, and Mars. This sensing technology may also improve a variety of earthbound applications such as climate and environmental observations, robotic maneuvering, topographical surveillance, and hazard avoidance systems for cars or aircraft.